

Social evolution of structural discrimination

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Structural discrimination appears to be a persistent phenomenon in social systems. We here outline the hypothesis that it can result from the evolutionary dynamics of the social system itself. We study the evolutionary dynamics of agents with neutral badges in a simple social game and find that the badges are readily discriminated by the system although not being tied to the payoff matrix of the game. The sole property of being distinguishable leads to the subsequent discrimination, therefore providing a model for the emergence and freezing of social prejudice.

I. INTRODUCTION

Structural discrimination between groups defined by easily observable characteristics is a key question of sociology. A century of research in social psychology has produced a rich literature on possible explanations and mechanisms [1–3]. The psychological perspective is complemented by a structural view in which discrimination is considered part of a path dependent community-level-state, largely determined by history [4]. In reality, discrimination is likely to be the result of a complex interplay between such mechanisms. In order to develop a better understanding of the individual mechanisms we here focus on one specific mechanism and ask:

“Could a social hierarchy emerge and persist between two groups distinguished by easily observable characteristics, even if they are identical in terms of intrinsic properties?”

In this paper we make a first attempt to approach that question using methods recently developed within the field of agent based social-evolutionary modeling. Starting from a game-theoretical model by Ohtsuki et al. [5], describing the evolution of cooperation in a public goods game on graphs, we introduce an absolutely meaningless yet observable binary marker. By allowing the agents to apply different strategies towards neighbours with different badges, but without introducing any psychological assumptions about preferences for doing so, we find that the evolution towards cooperation is dramatically changed. In particular we find for high selection pressure, the symmetry between badges is spontaneously broken, as both strategies of full cooperation and full defection are outcompeted by a strategy of defecting agent with one badge while cooperating with agents with the other.

II. THE MODEL

Let us define a game of agents distributed on a square grid, with periodic boundary conditions along one dimension to form a cylinder. Each agent has a static and binary ‘badge’, either green or blue, decided at the beginning of the game. This badge is the only observable

difference between agents. The agents interact with their nearest neighbours by either cooperating or defecting. When cooperating, an agent donates one unit of value to help the neighbour. To simulate the benefit of cooperation, the donation is scaled such that the neighbours’ payoff is increased by k . Defection is simply to not cooperate.

Since an agent cannot distinguish neighbours who have the same badge it must act the same way towards all of them. Thus the model has four possible strategies: “defect all”, “cooperate with all”, “cooperate only with green”, and “cooperate only with blue”.

The payoff of an agent is calculated as the sum of all donations received, subtracted with the donations given away:

$$p_i = \sum_{j \in \mathcal{N}_i} k \cdot S_j(b_i) - S_i(b_j),$$

where \mathcal{N}_i is the set of neighbours of agent i , $b_i \in \{\text{blue, green}\}$ is the badge of agent i , and $S_i(b_j) = 1$ if the the strategy of agent i is to cooperate with the badge worn by agent j , and $S_i(b_j) = 0$ if it is to defect.

The evolutionary dynamics of the spreading of the strategies is as follows. Every turn a random agent is chosen (from a uniform distribution over all agents). With a small probability μ , this agent will ‘mutate’, i.e. choose a new random strategy (from a uniform distribution over all strategies). Most times, however, the chosen agent will imitate the behaviour of one of its most successful neighbours. In that case, a neighbour is chosen with a probability proportional to its ‘fitness’, which is directly related to its payoff by:

$$f_i = e^{w \cdot p_i}$$

where f_i and p_i are the fitness and payoff of agent i , and w is a global parameter controlling the selection pressure. When the selection pressure is high, the neighbour with the highest payoff is very likely be chosen. When the selection pressure approaches zero, all neighbours are chosen with almost the same probability.

If all agents have the same badge and the mutation rate is set to zero, the model is qualitatively that described by Ohtsuki et al. [5], except that these authors used a fitness

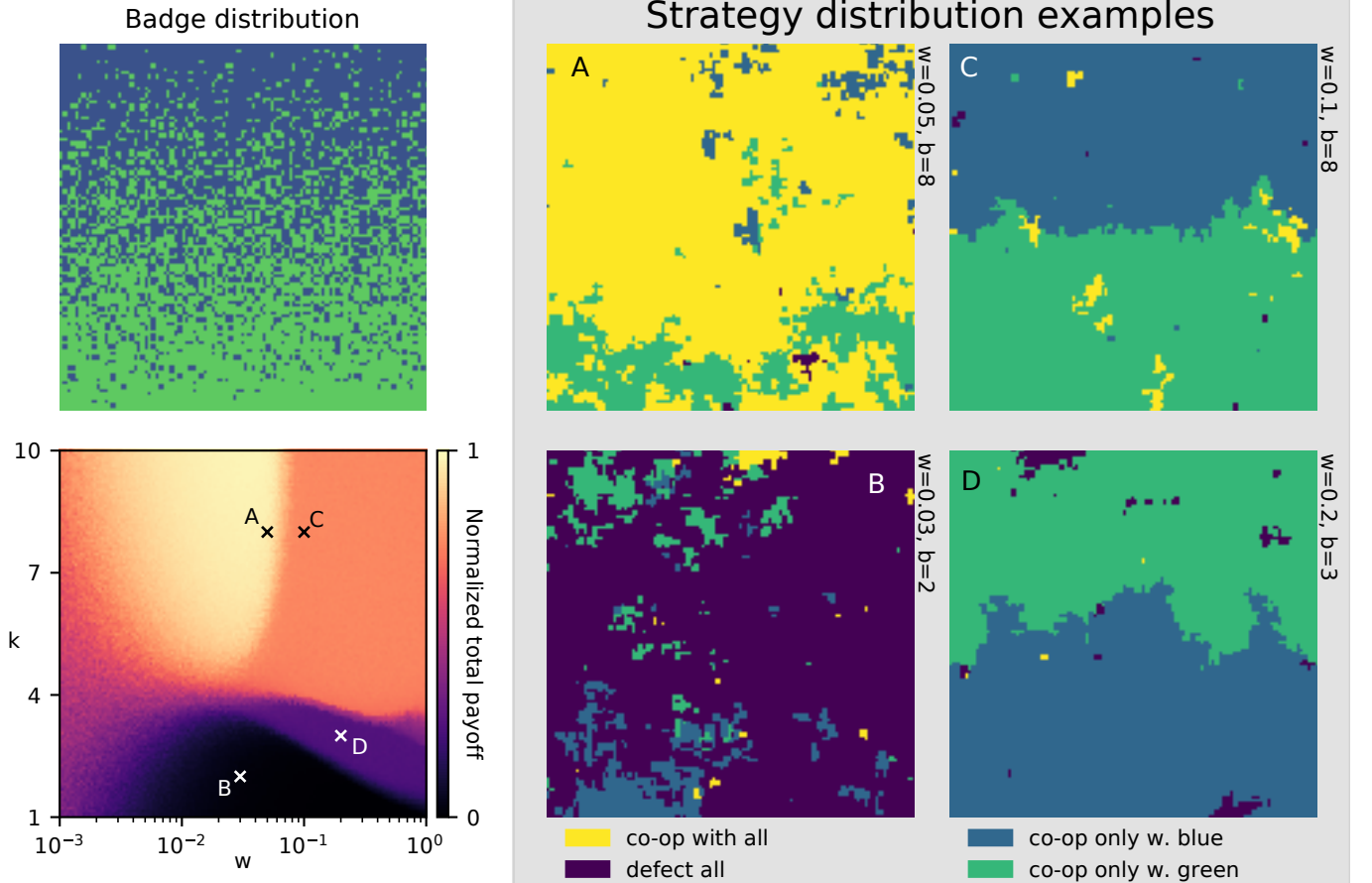


FIG. 1. Phase-diagram. Constant mutation-rate, $\mu = 0.001$. **Bottom-left:** Parameter scan over cooperation benefit k , and evolution pressure w . The color indicates the mean payoff normalized by b (maximal possible mean pay-off), averaged over 20 samples uniformly distributed over a period of 10^8 time steps. At each data point the system is initialized with all defectors and run for a transient period of 2×10^7 time steps before the mean payoff is measured. **Right:** Four snapshots of strategy-distributions at parameters corresponding to those marked in the parameter scan. **Top-left:** badge distribution used in each of the examples to the right. In the parameter scan, a new badge distribution is generated at every point, to ensure that the results are not unexpectedly caused by random local structures.

function $f = 1 - w + w \cdot p$, while we use an exponential function to ensure positive probabilities for all values of w . The difference is negligible in the limit $w \ll 1$.

Our model is characterized by three dynamical parameters: The cooperation benefit k , the evolution pressure w , and the mutation rate μ .

The random mutations serve two functions: Adding noise and preventing strategies from going extinct. We are interested in the evolutionary dynamics of the imitation dynamics, and not in the noise. Thus we keep the mutation-rate small and constant ($\mu = 0.001$ unless otherwise stated).

Besides the three parameters mentioned above, we have an extra ‘hidden’ parameter, namely the distribution of badges. We have chosen mainly to focus on a random distribution in which the probability that an agent is given a green badge increases linearly from zero in one end of the ‘cylinder’ (‘top’), to one in the other end (‘bottom’). This allows us to effectively average over a variety

of local configurations, as well as to investigate the effects driven by imbalanced badge density.

III. RESULTS

Figure 1 captures the long-term behaviour of the model, as it settles into different stationary states dependent on parameters. In the bottom left panel the normalized mean payoff is plotted (in color) as a function of the evolution pressure w and the cooperation benefit k . This is identical to the fraction of donations out of all possible ones. In this panel, we see four regions with distinct levels of cooperation. In the right panel, four examples of stationary state strategy distributions are shown, one for each phase.

A: The system is dominated by full cooperation resulting in close to maximal mean payoff. As expected, this optimal state requires that the cooperation benefit

is greater than 4 (average connectivity), as predicted by Ohtsuki et al. in ref [5]. Surprisingly, we find that it also requires relatively low selection-pressures.

B: The cooperation benefit is low and the dominant strategy is complete defection, resulting in approximately zero payoff. Surprisingly we find that when the evolution pressure is high ($w \gtrsim 0.03$), full defection is outperformed by strategies with non-zero cooperation even when the cooperation benefit is less than four (the average connectivity).

C: In general, when the evolution pressure is high, we observe that the system is dominated by the asymmetric cooperation-strategies. With our choice of badge distribution, the lattice of agents is split into two qualitatively different regions. In ‘the top’ of the cylinder, the large majority of agents have the blue badge, while in ‘the bottom’ the green badge is much more common. When the cooperation benefit is high, $k \gtrsim 4$ (average connectivity), there is a threshold for the evolution pressure, above which we find the dominating strategies in each of the two domains (‘top’ and ‘bottom’) are to cooperate with agents carrying the majority badge, while those in the minority are defected. The normalized mean payoff is approximately equal to the population fraction of the majority in each domain, i.e. $3/4$ given this specific badge-distribution.

D: For high evolution pressures and intermediate selection benefits k slightly below 4 (the average connectivity), we observe that domains of the asymmetric cooperation strategies have switched around as compared to the case with k above 4 (the average connectivity). Cooperating with agents carrying one badge, and defecting those carrying another, still outcompetes both of the symmetric strategies, but within each of the two domains (‘top’ and ‘bottom’) the majority is defected, and only the minority receive donations. Consequently the normalized mean payoff is equal to the fraction of minority badges within each domain, which is $1/3$ with the given badge-distribution.

Low selection pressure, high entropy Closer examination of the parameter scan in figure 1 reveals that the transition between the different phases are qualitatively different. For low selection pressure (left side of the figure), there is a smooth transition between ‘low mean payoff’ when the cooperation benefit is low, to ‘high mean payoff’ when the cooperation benefit is high. For intermediate cooperation benefits, we find very noisy stationary distributions in which patches of all possible strategies coexist. These high-entropy distributions are easy to understand. Because of the very low selection pressure the boundaries between strategy patches perform a random walk almost without a drift. When $w = 0$ dynamics are equivalent to a classical voter-model[6, 7] with four opinions.

The sharp phase transitions observed at higher selection pressures ($w \gtrsim 0.03$) are more intriguing because 1: the sharp transitions indicate that relatively small changes in the environment can have dramatic effects

on the social structure, and 2: this is where we see symmetry-breaking.

Breaking symmetry The most intriguing finding in this new model, is the symmetry breaking phase transition in which full cooperation is outcompeted by a strategy of selectively cooperating with agents carrying one of the badges but not with those carrying the other badge. Surprisingly, we find that, as long as the cooperation benefit is high (higher than a few times the average connectivity), symmetry breaking is controlled by the selection pressure, and full cooperation cannot be restored no matter how much the cooperation benefit is increased. To get a better understanding of this, we have performed a detailed study of a simple scenario.

In this example, all agents are arranged on a one-dimensional line. Each agent has only two neighbours, and all agents except one have the blue badge. The single agent with the green badge is placed in the middle of the line. We leave aside random mutations, and we choose that in one end of the line, the last agent will always have the strategy of full cooperation, while in the other end the last agent is stubbornly insisting on cooperating with blue, but defecting green. Any strategy squeezed in between these two will eventually disappear (by random fluctuation), and the complete state of the system can be described by the location of the boundary between one strategy and the other. Notice that outside the neighbourhood of the one green agent, these two strategies lead to identical behaviour, and thus the boundary between them will simply make an unbiased random walk. In the close vicinity of the green agent, however, the boundary will move left or right with a probability that must be calculated explicitly for each position. After having determined the individual stepping probabilities we calculate the stationary distribution of the boundary and compare the probability of finding it on the symmetric side of the green agent (the asymmetric strategy dominates) to that of finding it on the asymmetric side (the symmetric strategy dominates).

$$\frac{\mathcal{P}(\text{cooperation only with blue})}{\mathcal{P}(\text{full cooperation})} = \frac{2}{1 + e^{-2wb}} \frac{(1 + e^{-w})^2}{(1 + e^w)^2}$$

When the fraction is greater than one, we expect a strategy of asymmetric cooperation to be able to outperform the full cooperation in a mixed population. Comparison with the phase diagram for the one-dimensional system show a close, but non-perfect match (see supplementary figure VIC).

General graphs The model is defined solely by interactions with nearest neighbours, and it is straightforward to generalize it to arbitrary networks instead of a simple 2d square lattice. We have examined the behaviour on Erdős-Renyi random graphs with average connectivity 4. We find that the phase diagram is very similar that obtained from the 2d square lattice, with a uniform badge distribution. However, the phase transitions are more noisy (see supplementary figures VIA and VIB).

IV. DISCUSSION

Irrational agents It is worth pointing out, that the social evolutionary dynamics in our model lies very far from the traditional economics assumption of rational agents. Cooperating will always reduce an agents pay-off compared to defecting, and so the Nash-equilibrium of the model is trivially a state of complete defection independent of parameters (the tragedy of the commons). When the model allows cooperation to spread, it is because the evolutionary dynamics is based on imitation rather than an informed attempt at maximizing ones own payoff. Agents simply copy the behavior of successful neighbours without considering whether this behaviour will benefit themselves or not.

We have remained true to this irrationality when extending the model by introducing the concept of observable, but informationless, badges. In our model agents have no pre-assumptions about the meanings of badges, and they do not pay any attention to the color of their own badge when choosing between strategies. For example, if a green agent has a successful blue neighbour it will have no scruples adapting this neighbours strategy, even if it means to defect green and cooperate with blue. However, the green agent will put itself in a unfavorable situation by doing so, and therefore be very ineffective in relaying the strategy. In the real world, this would correspond to a person exhibiting more generous behaviour towards people appearing different [8].

Donate or steal? As described above, our model treats cooperation as an active choice, while defection is merely the passive lack of cooperation. However, this doesn't have to be the case. In fact the dynamics are invariant under adding any constant offset to the payoff of agents, since it would merely multiply the fitnesses of all agents by a constant factor, leaving the relative probabilities unchanged.

In particular, we could choose a constant offset of $-4(b - 1)$, corresponding to a system in which cooperation is the passive choice (donating zero), while defection is the choice of actively increasing your own payoff by one unit by 'stealing' k from the defected neighbour.

One could of course also imagine a scenario in which the constant offset is much bigger (say hundreds or thousands units of value), and the difference between strategies is solely a small variation in how much is donated. The dynamics still remain unaltered. We imagine that such small variations in investment readiness could model both conscious and subconscious biases [9].

Outlook The occurrence of discrimination correlated with visual observables, but unexplainable by any correlation with meaningful intrinsic properties, is a well known phenomenon with direct consequence for our society on an individual, as well as a structural level. In this paper we demonstrate that introducing visual badges in a simple model of social interaction, can result in surprising and dramatic changes of model behaviour: The emergence of social discrimination from the social systems' dynamics itself on the basis of neutral observables, only.

We believe that continuing this work by investigating the effects of observable, but meaningless, badges in a wider range of evolutionary dynamics models of social interaction will reveal valuable insights about the emergence of social structures.

V. ACKNOWLEDGMENTS

This work was directly inspired by a talk by Dr. Elizabeth A. Hobson at the Interdisciplinary Symposium for "Experiments and Models of Social Networks: Cooperation, Conflict and Trust" in Copenhagen, May, 2016. The talk combined theoretical modeling of status-signaling badges with direct empirical data from experimental behavioral studies of captive monk parakeets. [10].

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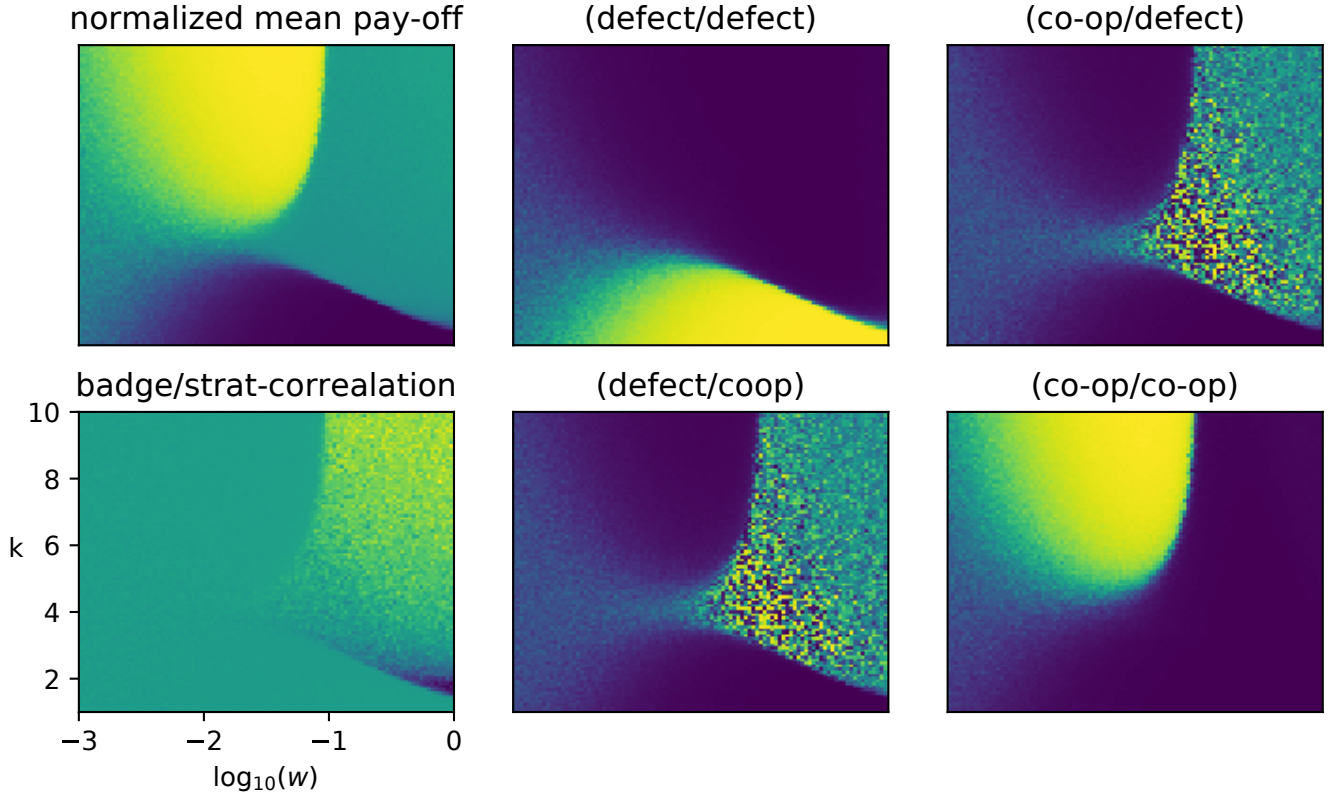
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VI. SUPPLEMENTARY FIGURES

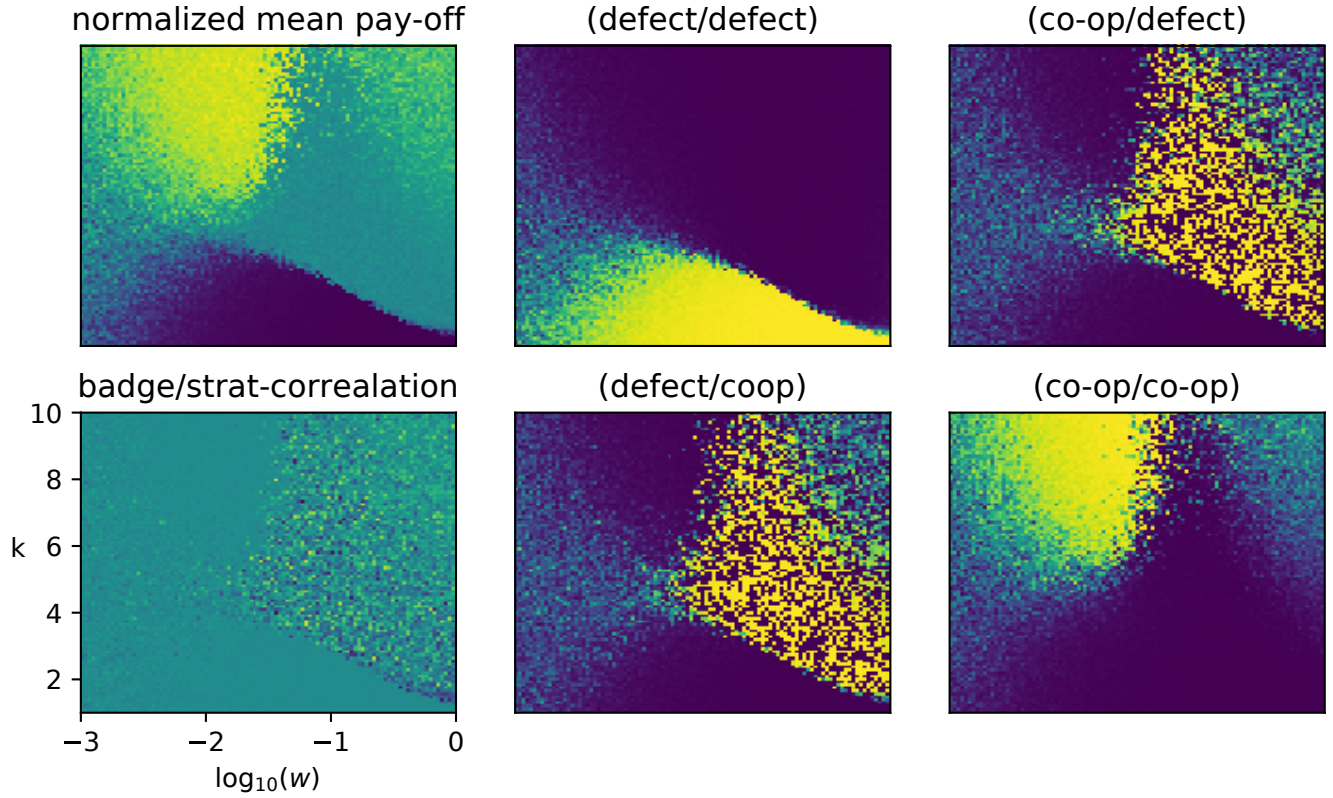
All panels in all figures below show parameter scans. ‘badge/strat-correlation’ measures to what extent agent positively discriminate their own badge. Add one for every agent who has a cooperating strategy towards their own badge, and subtract one for each agent cooperating with the badge they don’t carry themselves.

A. Uniform badge distribution



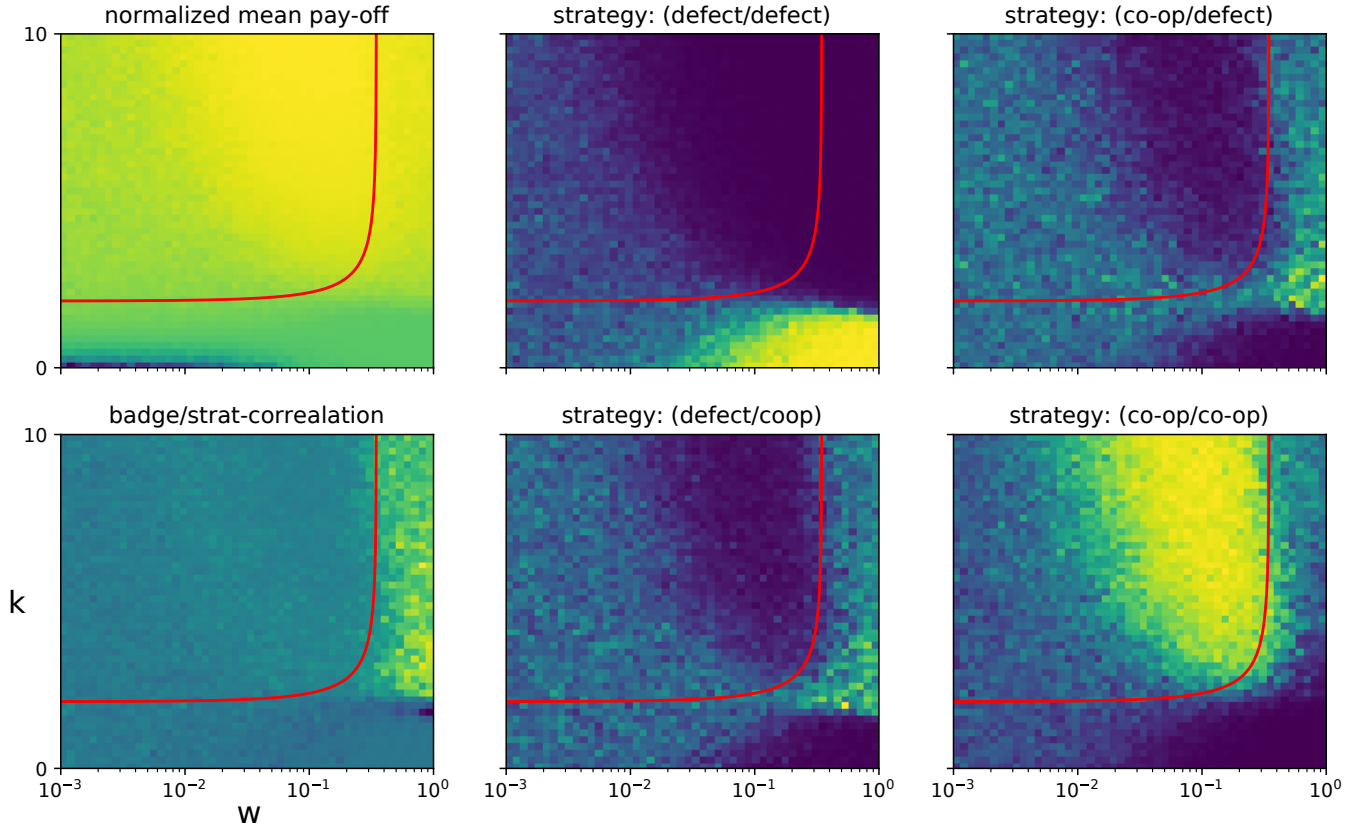
Differs from the model described in the main text only by having a uniform badge distribution. Every agent has 50/50 percent chance of being blue or green. The badge distribution is random and redrawn from a uniform distribution at every data point.

B. Erdős-Renyi graphs



Rather than putting the agents on a square grid, we here arrange them on Erdős-Renyi random graphs with 1000 agents and an average connectivity of $k = 4$. A new random graph is chosen at every data point. The badge distribution is random and redrawn from a uniform distribution at every data point.

C. 1D - Ring



For comparison with the theoretically predicted phase-transition mentioned in the paper (red line), we here show what the phase diagram looks like for a 1D system, i.e. a line of agents with two neighbours each, closed at the ends to form a ring. The badge distribution is random and redrawn from a uniform distribution at every data point.